DETERMINATION OF 3D DISPLACEMENT FIELD IN BEARING AND PULL-THROUGH STRUCTURAL LOADING OF SANDWICH INSERTS

Charles S. Hill
NASA JSC M&P

Ovidio Oliveras
Jacobs ESCG

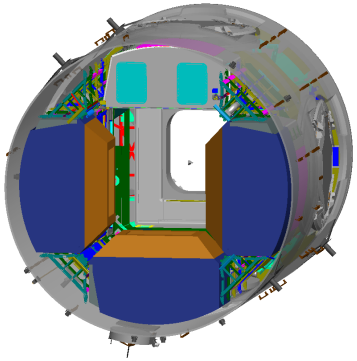
Displacement Field in Sandwich Insert Structural Loading

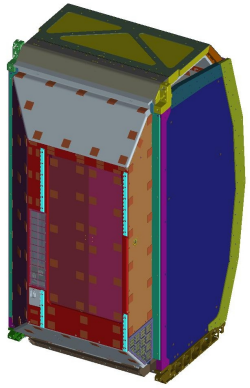
- Introduction
  - Existing Project Data
    - ISS CQ Tests from 2008
  - Relevance to Sandwich Composites Community
    - Need Data and Standard Test Methods
- Design Development Tests
- Flight Qualification Tests
- Experimental
  - Specimen Configuration
  - NDE Inspections
  - Bearing Fixture and Pull-Through Fixture
  - ARAMIS Strain Field Measurement
- Results
  - Displacement Field Frame Before Break
  - Strain vs Time at Stage Points
  - Displacement Field Throughout Loading Animation
  - Strength Values
- Conclusions
  - Full Scale Qualification Article Structural Test Passed 1.2 x Limit Load

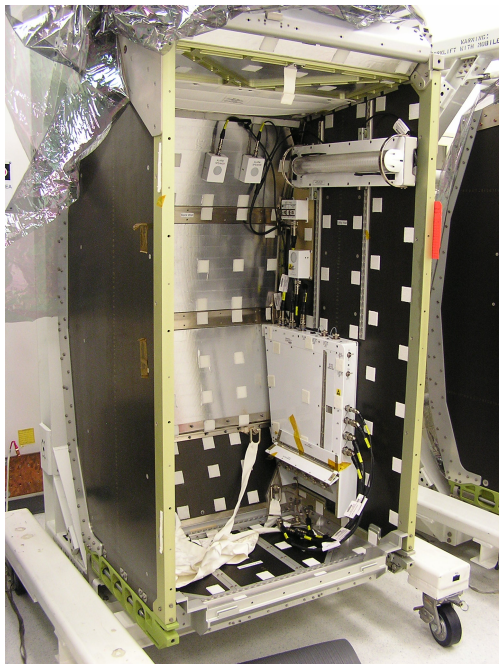
Displacement Field in Sandwich Insert Structural Loading

• Introduction -- Existing Project Data

- ***ISS Habitability Project Crew Quarters***
  - **Node 2 Rack Assembly**
  - **Composite Sandwich Structure Side Walls and Floor**
  - **Design Allowable Property Verification for CMH-17 Published Material System**







S126E008372

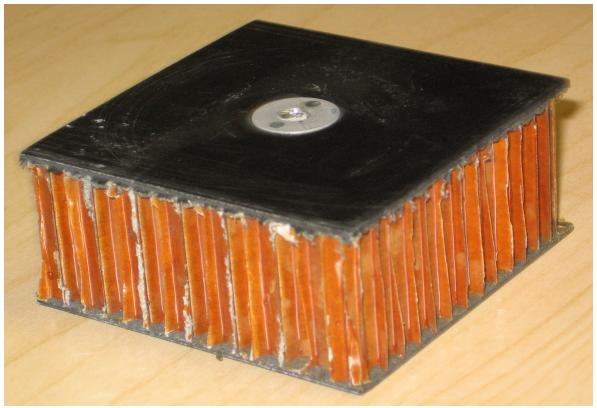
Displacement Field in Sandwich Insert Structural Loading

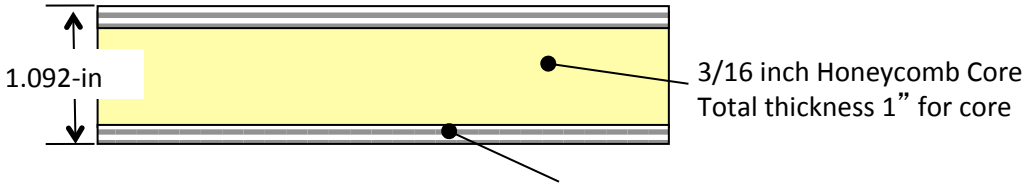
- Introduction
  - Availability of Strength Data for Inserts is Lacking
  - Intention to Provide Data for Publication
    - Issues with failure modes in initial configuration provided conservative minimum strength but not direct measure of insert property.
      - Tab/Support Adhesion Failures
      - Fastener Yielding
    - Improvement in potting/installation procedures.
      - Increased potting diameter
      - Reduced porosity

Displacement Field in Sandwich Insert Structural Loading

• Material Details

- 8-ply carbon fiber/epoxy quasi-isotropic [0,90,+/-45]2s uni-tape laminate.
  - AS4/3501-6; 33%RC; 145AW; 54" Hexcel
- Fiberglass scrim cloth finish on face sheet.
  - 1080/3501-6; Hexcel
- Nomex honeycomb core:
  - PN2-3/16-3.0; Plascore
  - FM73 Epoxy Film Adhesive
- Baking of panel for 24 hrs. at 120F per JSC PRC-9010.
  - Mitigation of marginal offgassing toxicity results.
  - ~150lbs of sandwich structure total for all 4 CQ's)



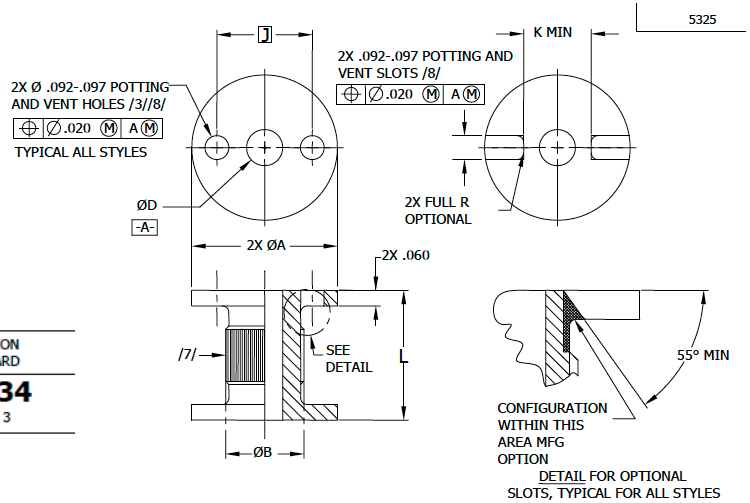


1 layer scrim, 8 layers of unidirectional carbon fiber (quasi-isotropic oriented), 1layer scrim
Total thickness 0.045" for outer skin

Sandwich Insert Types

NAS1834
Through Hole Insert

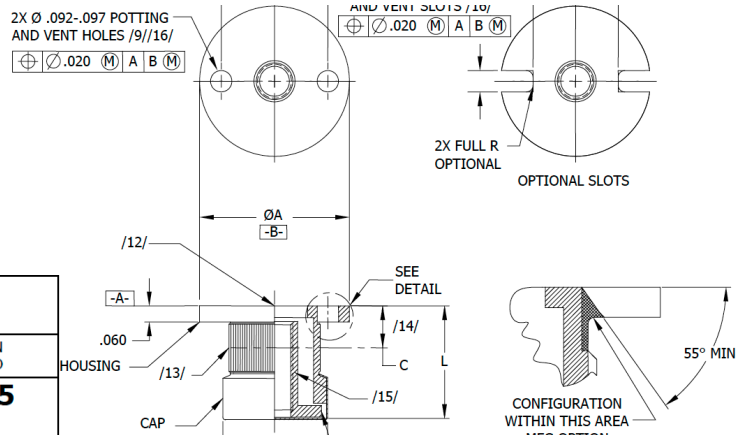
THIRD ANGLE PROJECTION	CUSTODIAN	REVISION
	NATIONAL AEROSPACE STANDARDS COMMITTEE	6
PROCUREMENT SPECIFICATION	TITLE	CLASSIFICATION PART STANDARD
NONE	**INSERT, MOLDED IN, CSK AND THRU CLEARANCE HOLE, SANDWICH PANEL**	**NAS1834**
		SHEET 1 OF 3



THRU CLEARANCE HOLE STYLE

NAS1835
Blind Threaded Insert

THIRD ANGLE PROJECTION	CUSTODIAN	REVISION
	NATIONAL AEROSPACE STANDARDS COMMITTEE	8
PROCUREMENT SPECIFICATION	TITLE	CLASSIFICATION PART STANDARD
NONE	**INSERT, MOLDED IN, BLIND THREADED, SELF-LOCKING, NONSELF-LOCKING, FLOATING, SANDWICH PANEL**	**NAS1835**
		SHEET 1 OF 3



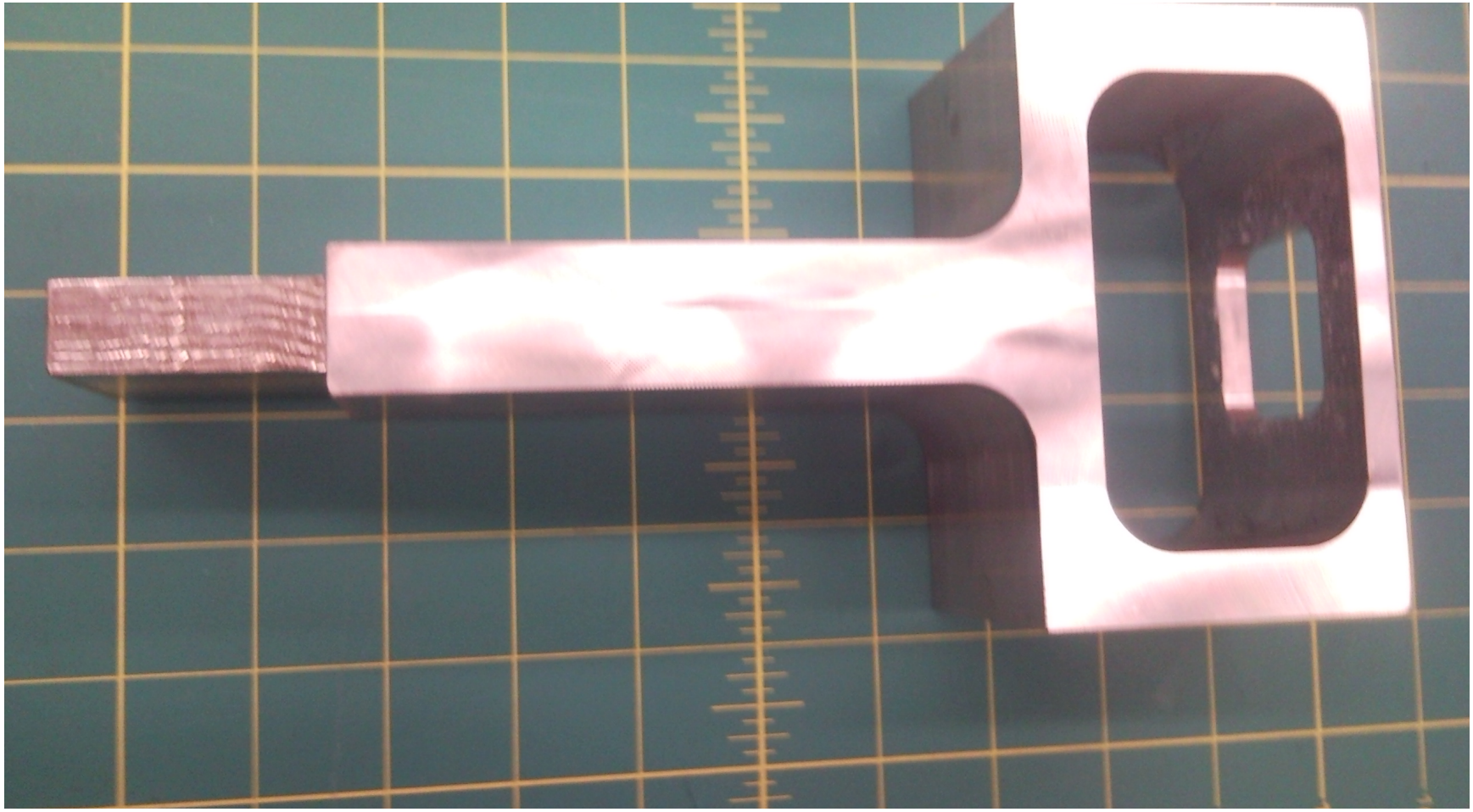
Displacement Field in Sandwich Insert Structural Loading

- Experimental
  - Development Tests
    - ~100 individual coupons
    - Range of insert diameters
    - Varied distance to edge to locate effective minimum
    - Bonded Aluminum Bar “tabs” for shear loading
      - Problematic due to alignment precision and peel mode
      - Large insert coupons failed the mounting tabs
      - Small inserts displayed fastener yielding
      - Usable data but not all measurements of insert property
    - Insufficient Fill of Epoxy Potting

Design Development Tests
Shear Tear Out (STO) Fixture

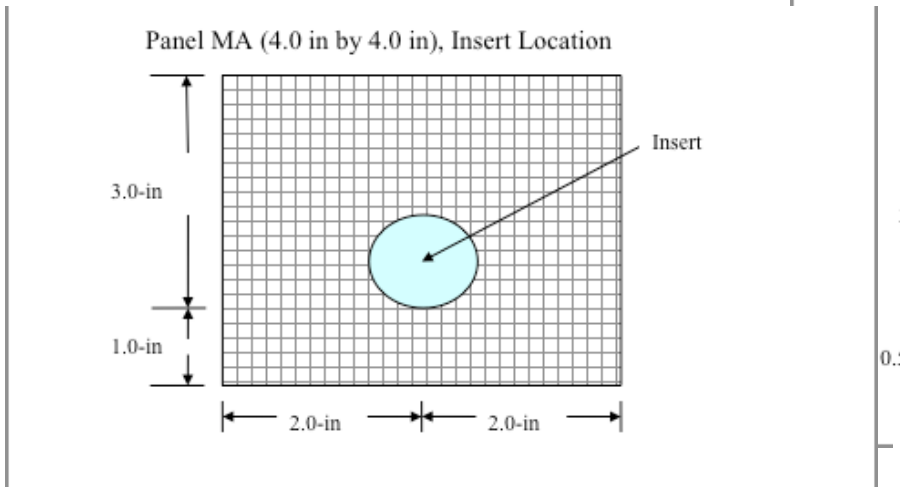
Development Sandwich Insert Sub-element Bearing Mechanical Property Test

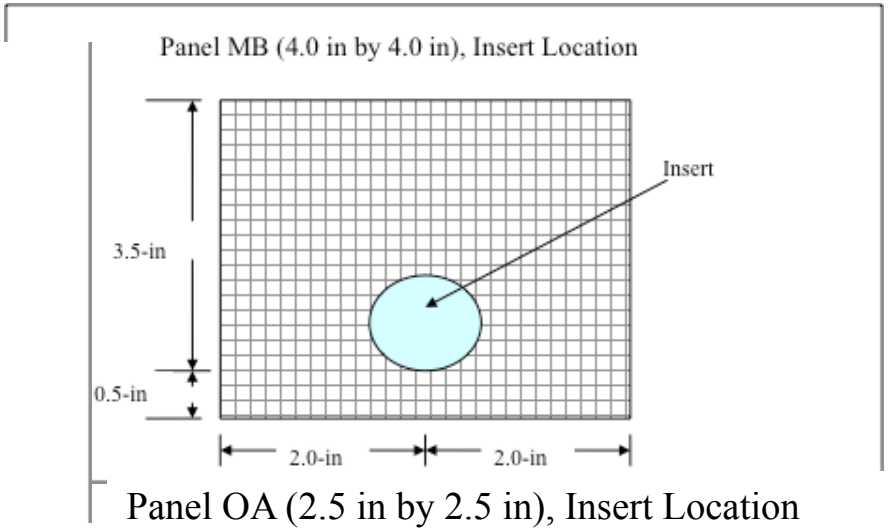
Design Development Tests Pull-Through (PO) Fixture

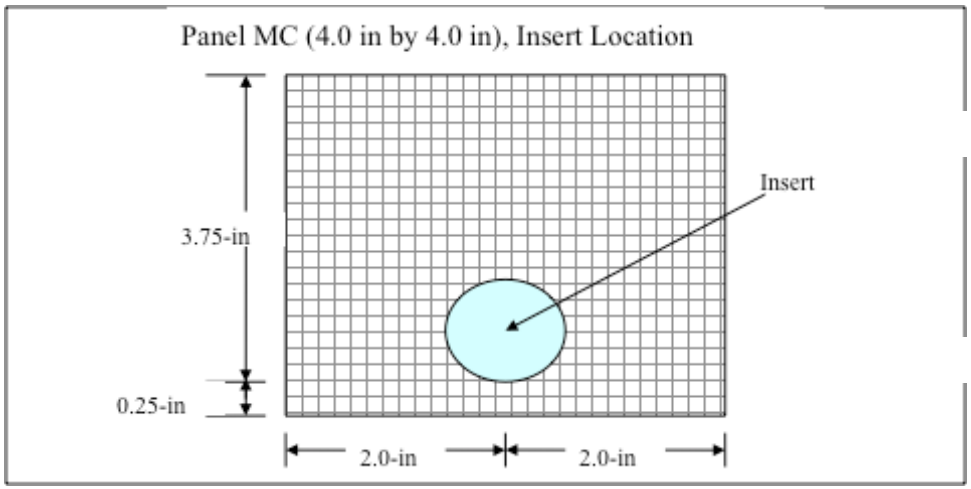


2”x2” Square Window with ½” Radius Corners

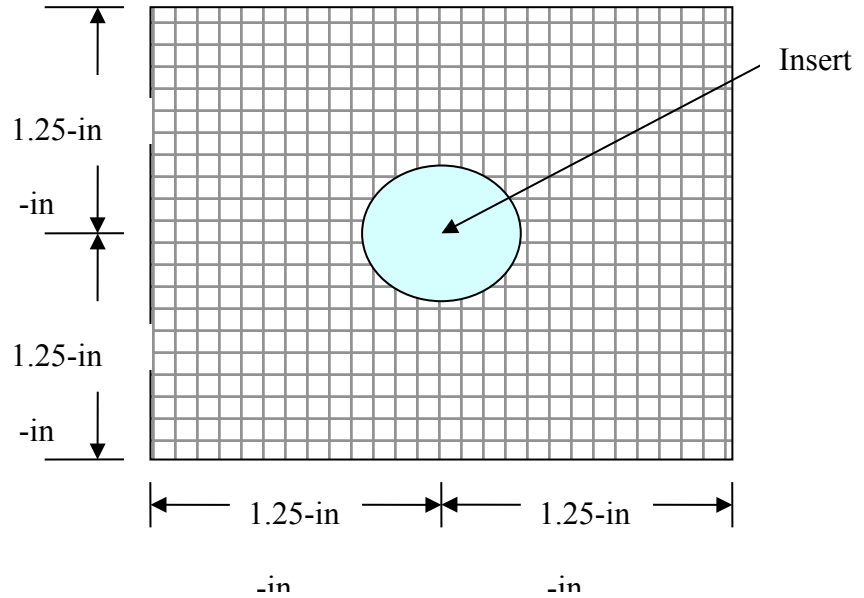
Development Test Specimen Dimensions STO and Pull-Thru







Panel OA (2.5 in by 2.5 in), Insert Location



Development Results STO

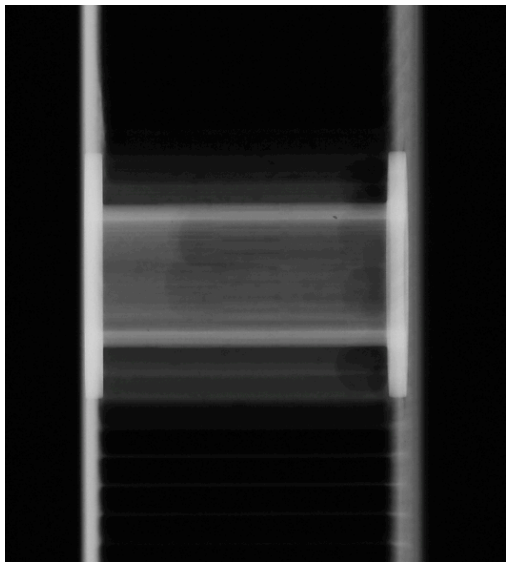
Sample Number	Description	Test Type	Spec#	Failure Mode	Peak Load [Lbs]
MCS-U-4	Panel MC NAS1832A3-4	0.25" Shear Bearing	1	tear out	1290
			2	tear out	1346
			3	tear out	1474
MBS-U-4	Panel MB NAS1832A3-4	0.5" Shear Bearing	1	tear out	1474
			2	bolt shear	1375
			3	tear out	1808
MAS-U-4	Panel MA NAS1832A3-4	1" Shear Bearing	1	bolt shear	1916
			2	bolt shear	1908
			3	tear out	1592
MCS-U-6	Panel MC NAS1834A4-1080	0.25" Shear Bearing	1	tear out	
			2		
			3		
MBS-U-6	Panel MB NAS1834A4-1080	0.5" Shear Bearing	1	tab adhsv	3112
			2	tab adhsv	2187
			3	tab adhsv	2179
MAS-U-6	Panel MA NAS1834A4-1080	1" Shear Bearing	1	tab adhsv	2886
			2	tab adhsv	2446
			3	tab adhsv	2699
MCS-U-5	Panel MC NAS1834A3-1080	0.25" Shear Bearing	1	tab adhsv	2703
			2		
			3	tear out	2259
MBS-U-5	Panel MB NAS1834A3-1080	0.5" Shear Bearing	1	tear out	2911
			2	tab adhsv	1716
			3	tab adhsv	1337
MAS-U-5	Panel MA NAS1834A3-1080	1" Shear Bearing	1		
			2		
			3	tab adhsv	1986

Sample Number	Description	Test Type	Spec#	Failure Type	Peak Load [Lbs]
MCS-U-3	Panel MC, NAS1835C6S	0.25" Shear Bearing	1	tear out	2131
			2	tear out	
			3	tear out	
MBS-U-3	Panel MB NAS1835C6S	0.5" Shear Bearing	1	tear out	2294
			2	tear out	1847
			3	tear out	2115
MAS-U-3	Panel MA NAS1835C6S	1" Shear Bearing	1	core bond	2540
			2	tear out	3080
			3	tear out	2541
MCS-U-2	Panel MC NAS1835C4S	0.25" Shear Bearing	1	tear out	1757
			2	tear out	2077
			3	tear out	2040
MBS-U-2	Panel MB NAS1835C4S	0.5" Shear Bearing	1	al. bars	1108
			2	tear out	1602
			3	tear out	1475
MAS-U-2	Panel MA NAS1835C4S	1" Shear Bearing	1	tear out	2347
			2	tear out	2127
			3	tab failure	1418
MCS-U-1	Panel MC NAS1835C3S	0.25" Shear Bearing	1	tear out	1254
			2	tear out	1190
			3	tear out	1310
MBS-U-1	Panel MB NAS1835C3S	0.5" Shear Bearing	1	tear out	
			2	tear out	
			3	tear out	1383
MAS-U-1	Panel MA NAS1835C3S	1" Shear Bearing	1	tear out	
			2	tear out	1557
			3	tear out	1521

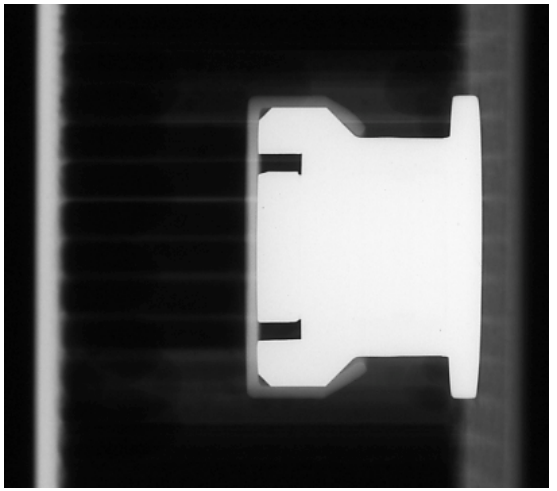
Development Results Pull-Thru

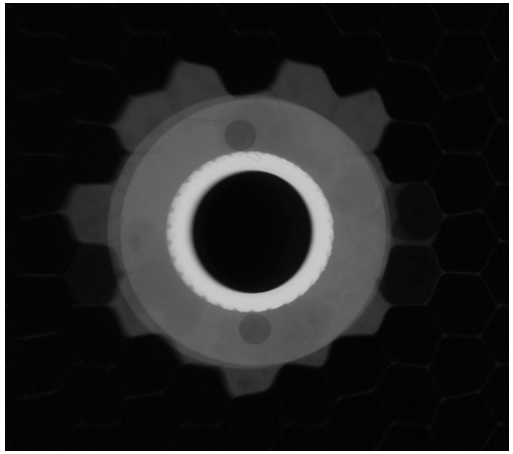
Sample Number	Description	Test Type	Specimen	Failure Type	Peak Load [Lbs]
OAS-U-3	Panel OA NAS1835C6S	pullout	1	epoxy to core	1427
			2	epoxy to core	1232
			3	epoxy to core	1632
OAS-U-2	Panel OA NAS1835C4S	pullout	1	epoxy to insert	852
			2	epoxy to core	879
			3	epoxy to insert	1084
OAS-U-1	Panel OA NAS1835C3S	pullout	1	insert	572
			2	insert	558
			3	epoxy to insert	533
OAS-U-7	Panel OA NAS1834A6-1080	pullout	1	epoxy to core	1396
			2	epoxy to core	1193
			3	epoxy to core	1441
OAS-U-4	Panel OA NAS1832A3-4	pullout	1	epoxy to core	745
			2	epoxy to core	752
			3	epoxy to core	832
OAS-U-6	Panel OA NAS1834A4-1080	pullout	1	epoxy to core	896
			2	epoxy to core	861
			3	epoxy to core	881
OAS-U-5	Panel OA NAS1834A3-1080	pullout	1	epoxy to core	791
			2	epoxy to core	783
			3	epoxy to core	818

Displacement Field in Sandwich Inserts X-ray Inspection NDE

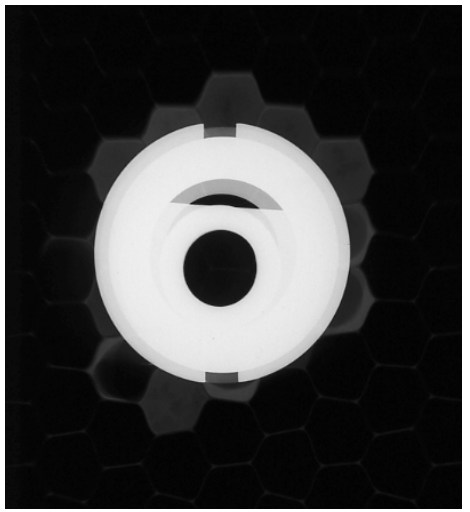


Development Test Coupons
Indicated Insufficient Fill
Of Epoxy Potting



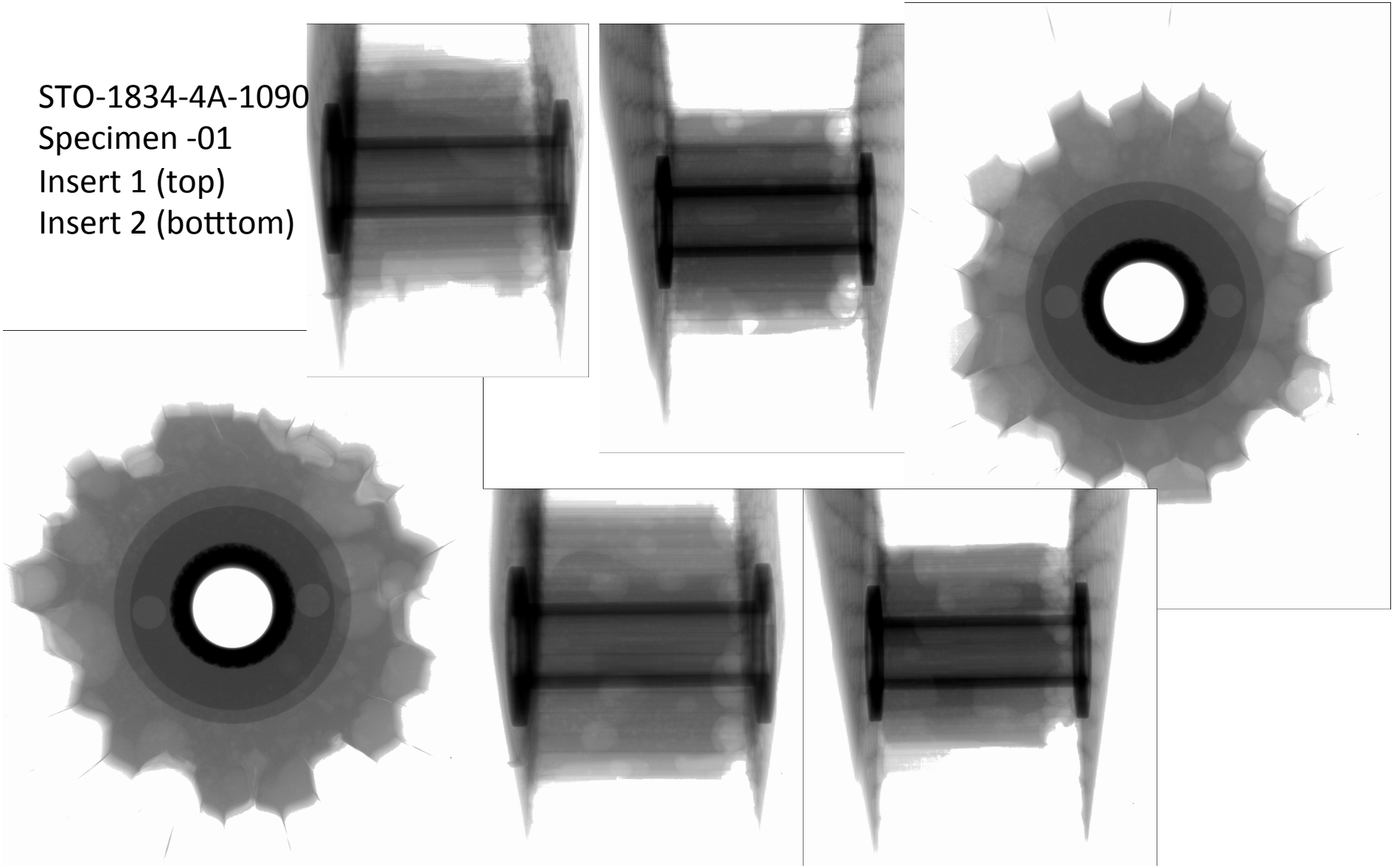


Installation Procedures
Improved for Flight Hardware
And Verification Panels



Qualification Test NDE X-Ray

STO-1834-4A-1090
Specimen -01
Insert 1 (top)
Insert 2 (botttom)



Displacement Field in Sandwich Inserts X-ray Inspection NDE

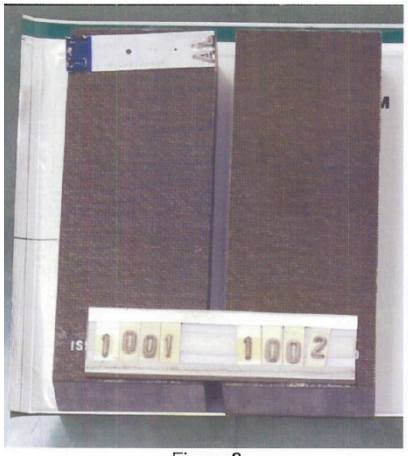


Figure 3

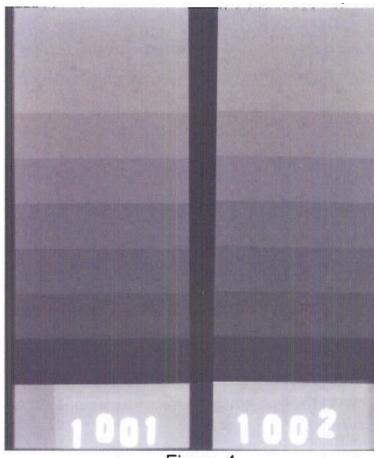


Figure 4

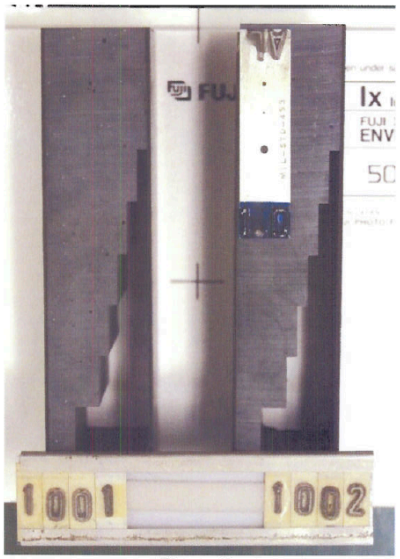


Figure 5

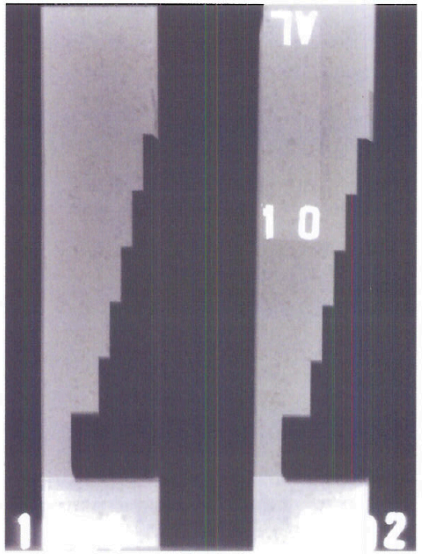


Figure 6

NDE Standard X-ray
Density Calibration Standard

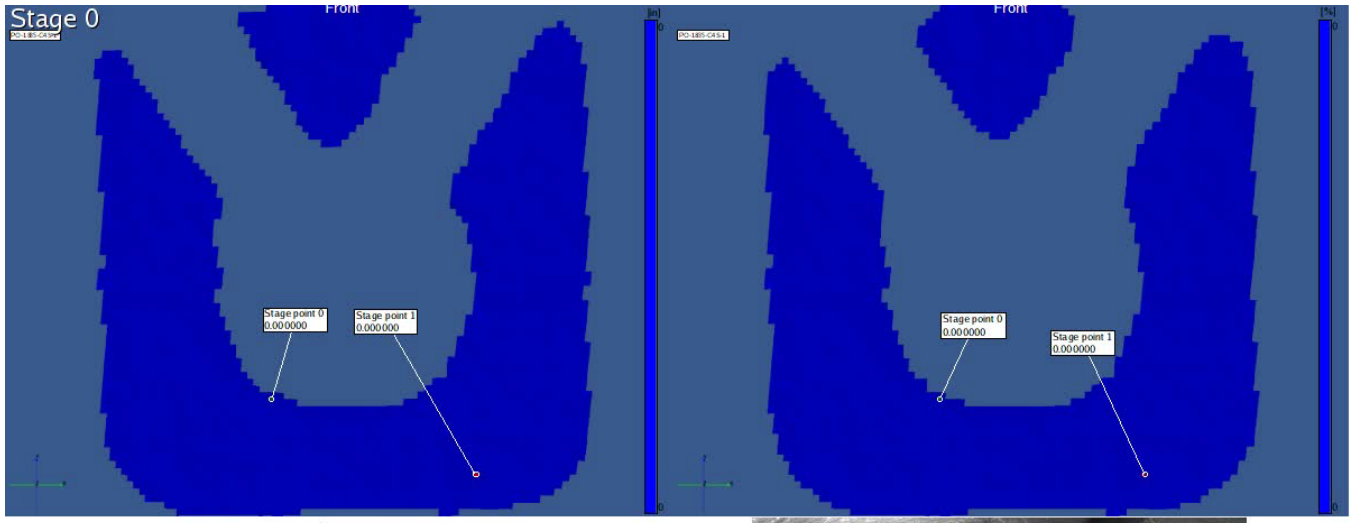
Epoxy Step Wedge Thickness Data & Density Measurements

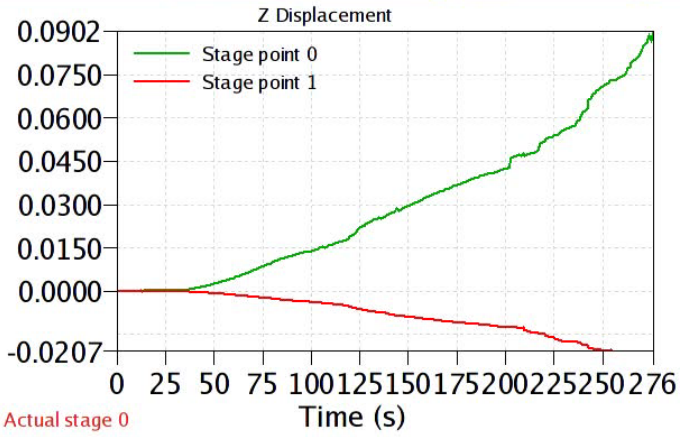
Print Dimension	S/N 1001	Film Density	S/N 1002	Film Density
1.00	0.995	1.44	0.992	1.46
0.90	0.895	1.58	0.895	1.60
0.80	0.795	1.70	0.789	1.72
0.70	0.695	1.84	0.685	1.85
0.60	0.589	1.98	0.584	1.97
0.50	0.485	2.14	0.484	2.15
0.25	0.236	2.63	0.234	2.64
1.00	0.995	N/A	0.980	N/A

Displacement Field in Sandwich Insert Structural Loading

- Experimental
  - Qualification Property Evaluation Tests
    - Equivalent Opposed Inserts for Shear
    - 5 coupons for each configuration in flight design
    - Full NDE inspection by X-ray
      - Top and Edge Views
    - ARAMIS Displacement Field Measurement
    - B-basis calculations for design strength
      - Property Allowable Requirement for Secondary Structure

Displacement Field in Sandwich Insert Pull-Through Loading



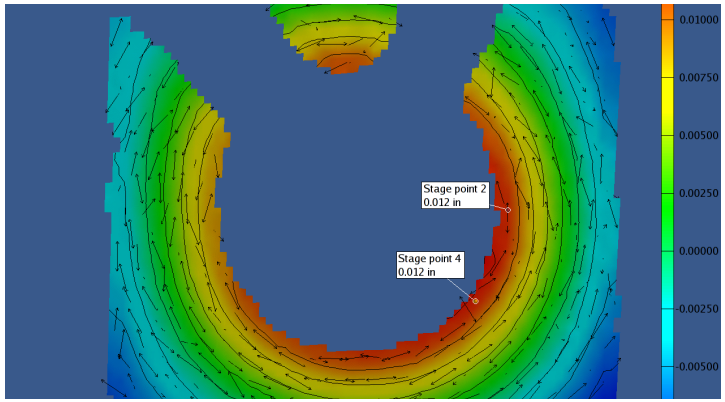


Left Camera with Strain Overlay

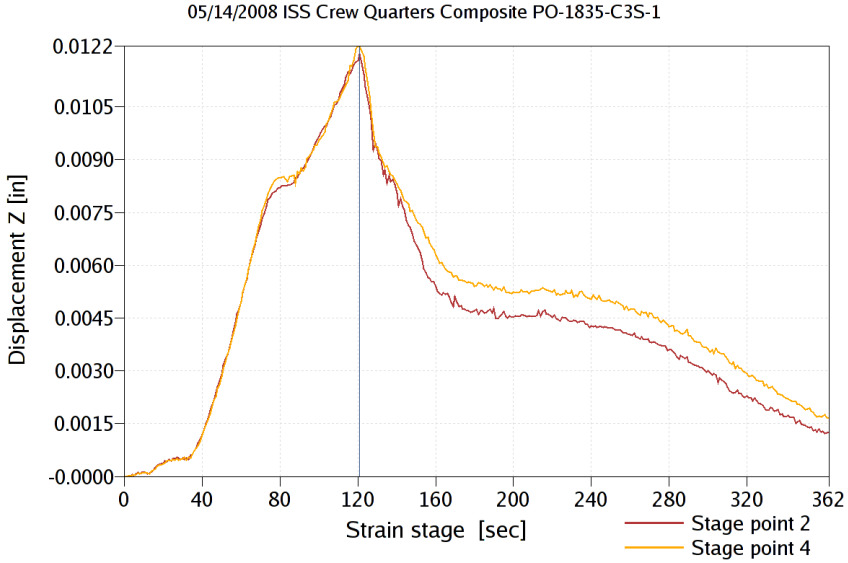
JSC NDE

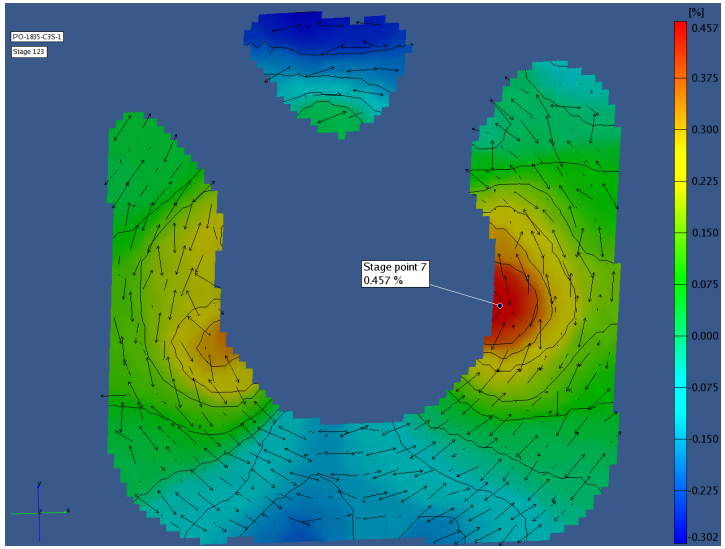
PO-1835-C4S-01 Report Animation

X, Y, Z Displacements at Break

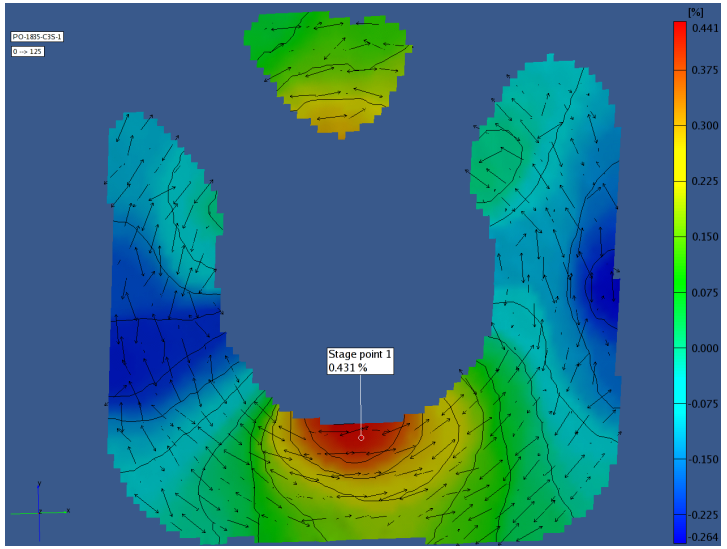


Displacement Z-field



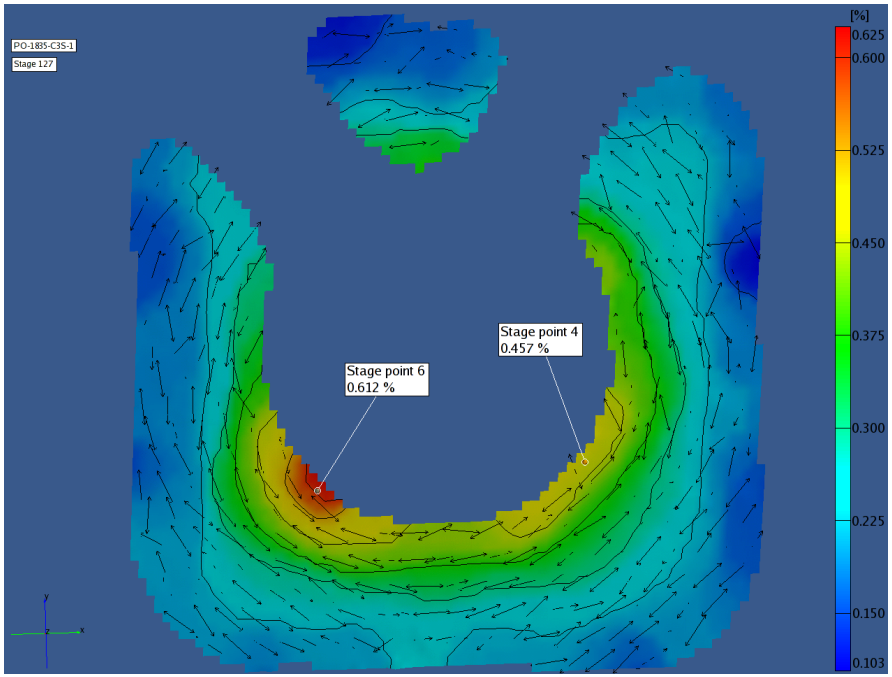


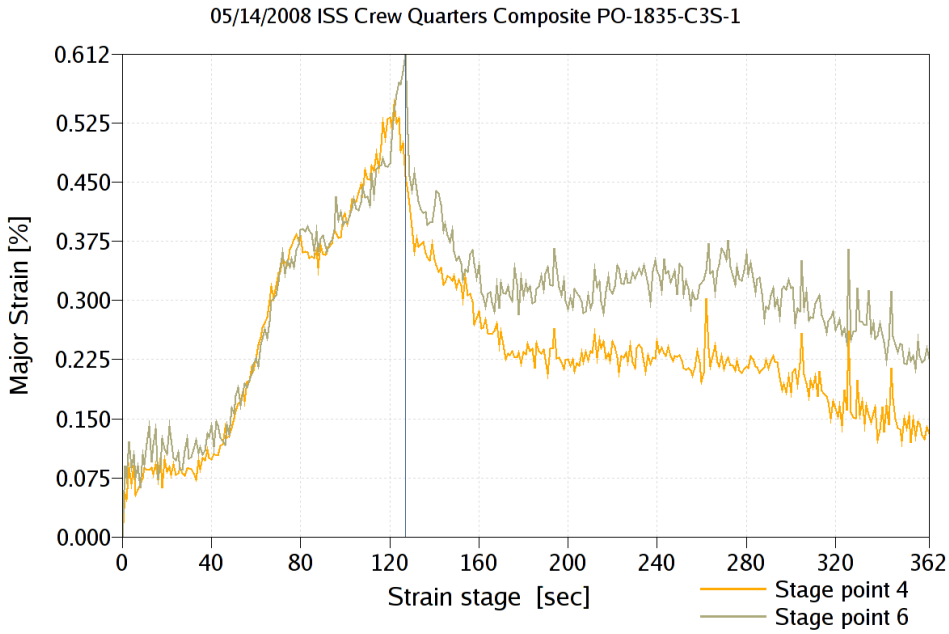
Displacement Y-field



Displacement X-field

Major Strain Field and Stage Point Strain vs Time

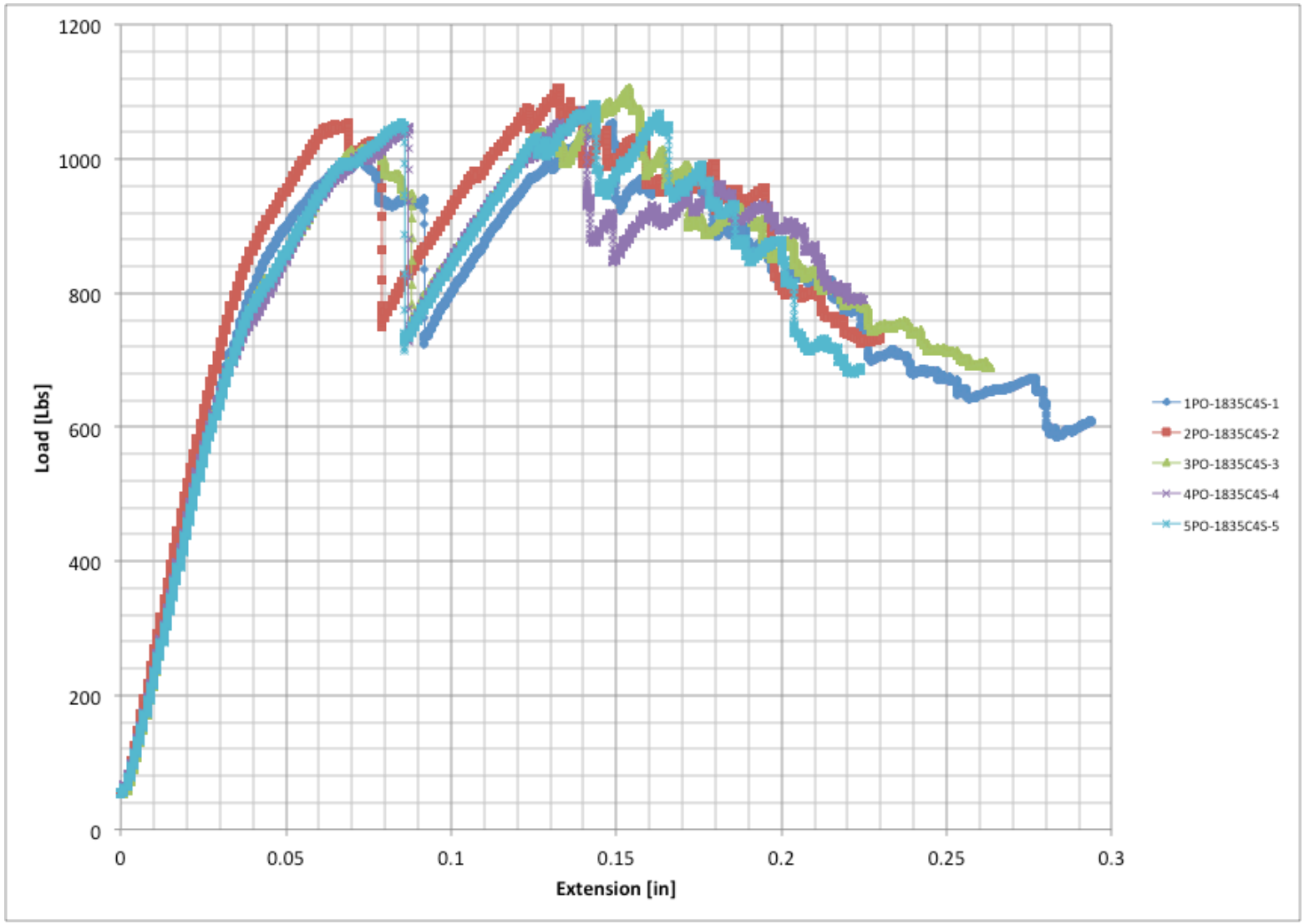




PO-1835-C3S-01

Major Strain Field at Break with % Strain vs Time at Stage Point Locations 4 and 6

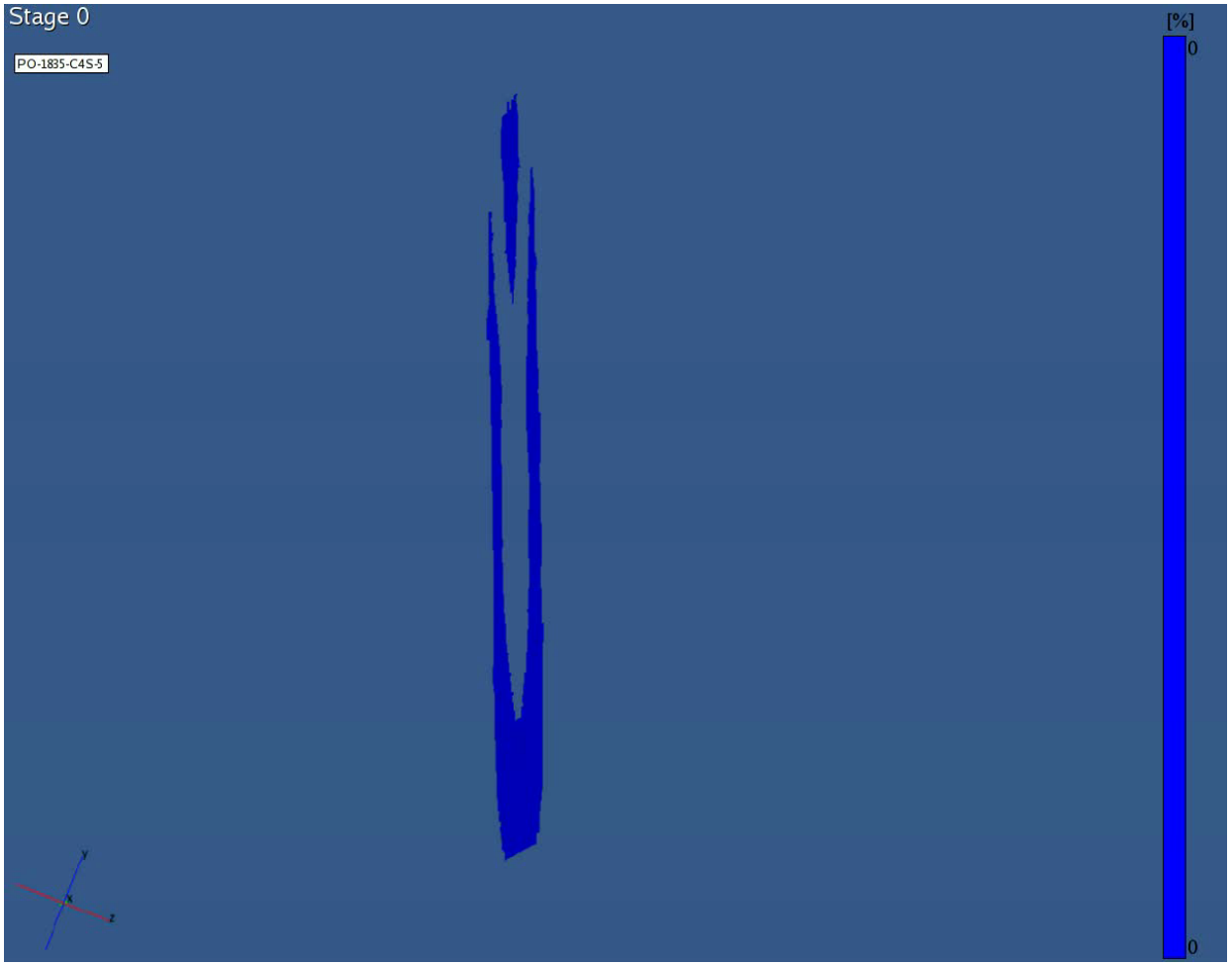
Load-Extension Plots for Pull-Through of PO-1835-C4S 01-05



Major Strain Field and Direction Evolution During Loading Event

Specimen PO-1835-C3S-01

3D Displacement Side-View Construction NAS1835-C4S

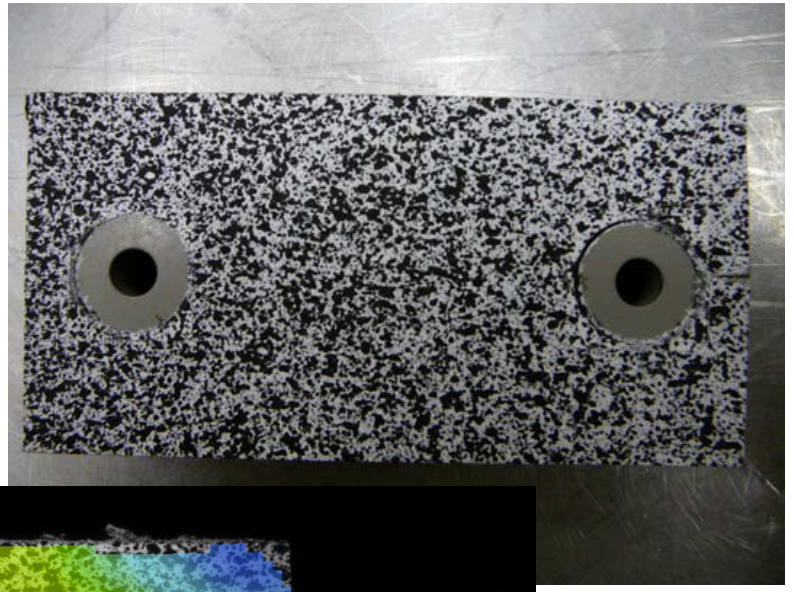


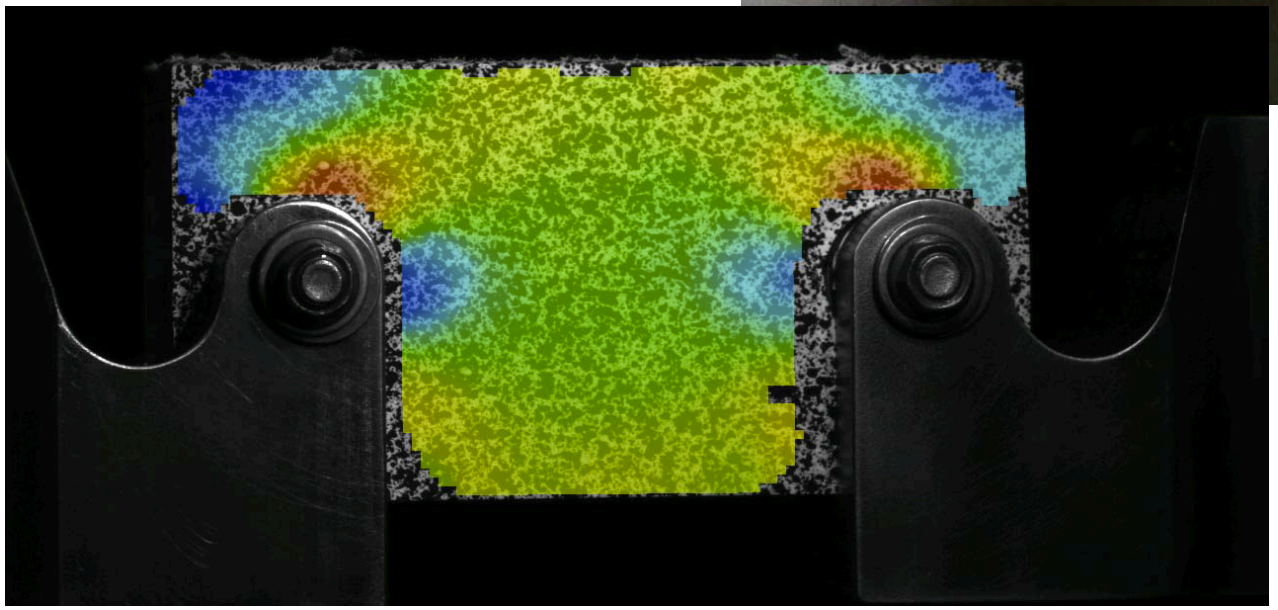
Specimen PO-1835-C4S

Displacement Field in Sandwich Inserts Under Bearing Load

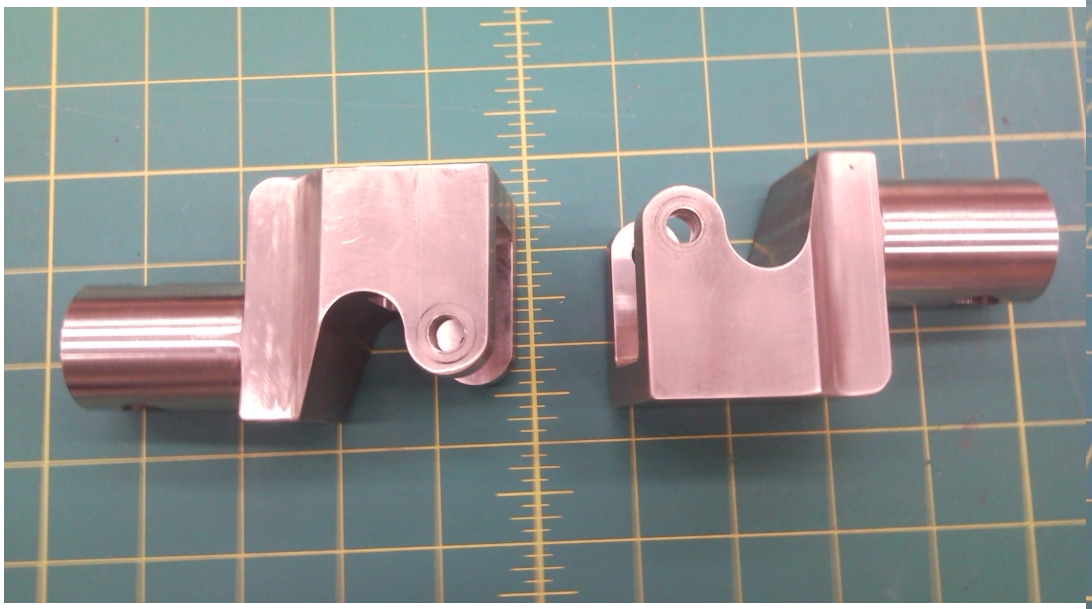
- NAS1834-A5-1090
- 5 specimens with two large through inserts on a composite honeycomb sandwich were use for bearing test.
- Specimen dimensions are 4” x 2” x 1”.
- Specimen was spray painted with a white and black speckle pattern.
- All specimens where pulled to failure.

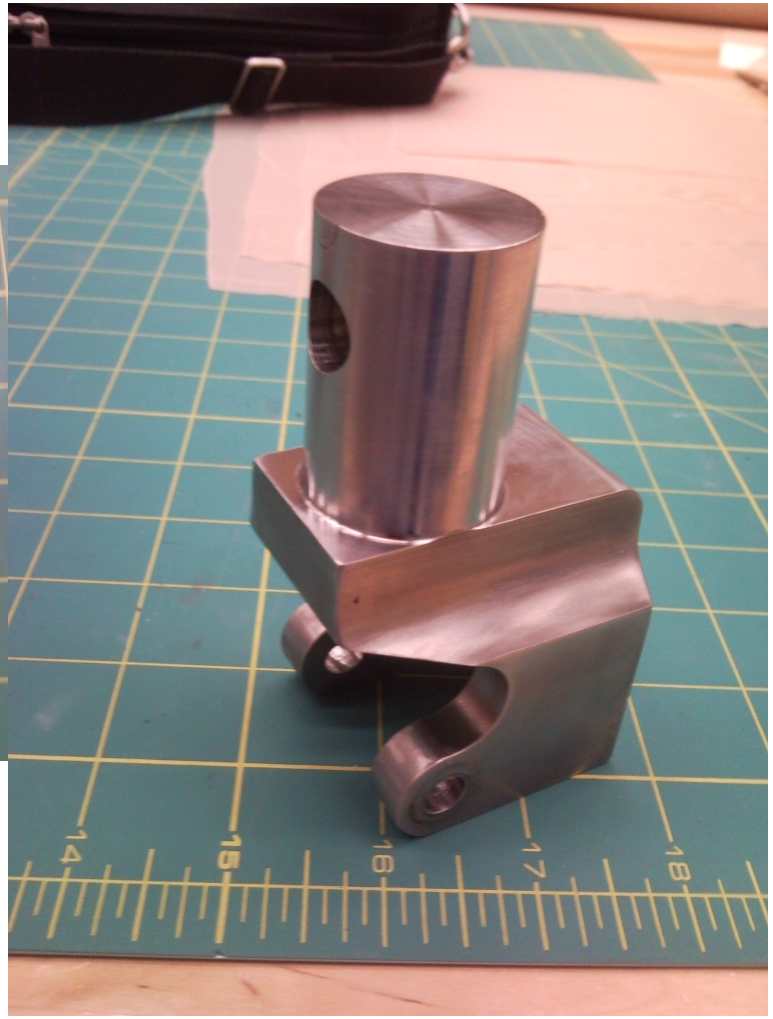
Displacement Field in Sandwich Inserts Under Bearing Load



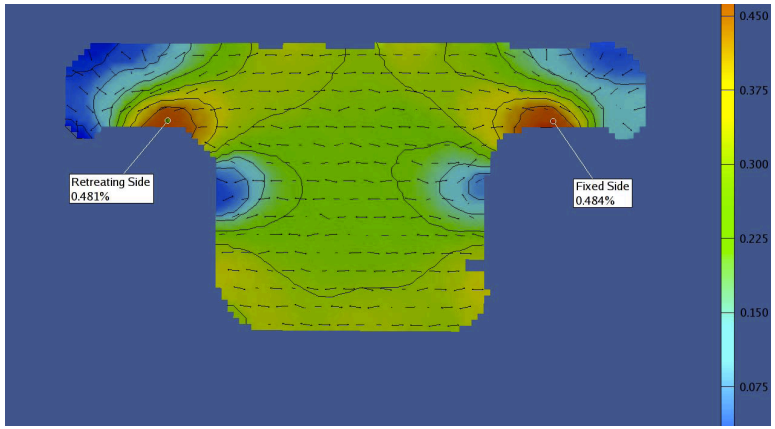


Bearing Fixture Designed for 180° View of Insert Edge

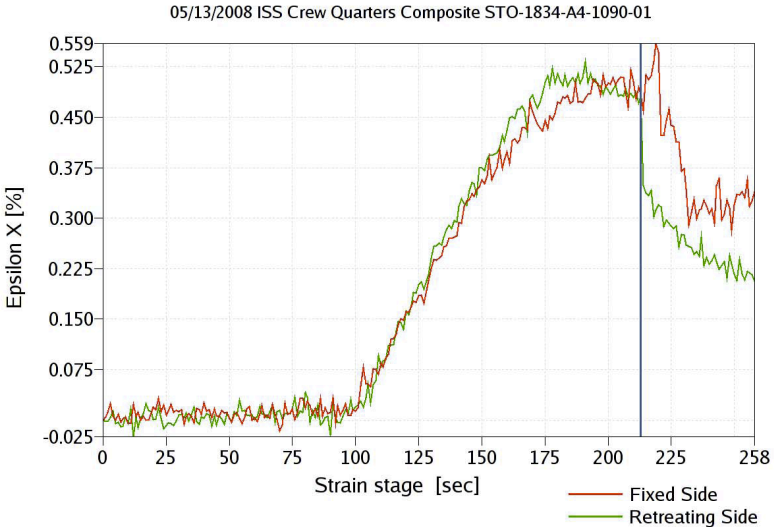


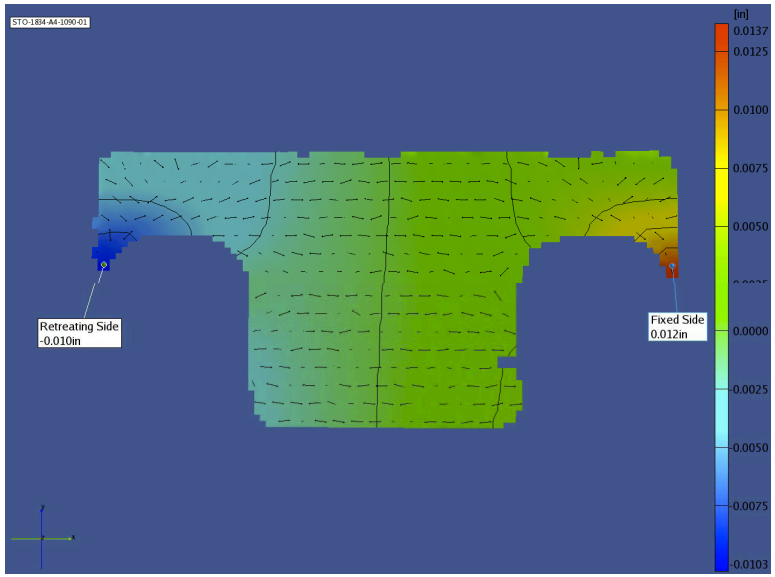


Displacement Field in Sandwich Inserts Under Bearing Load

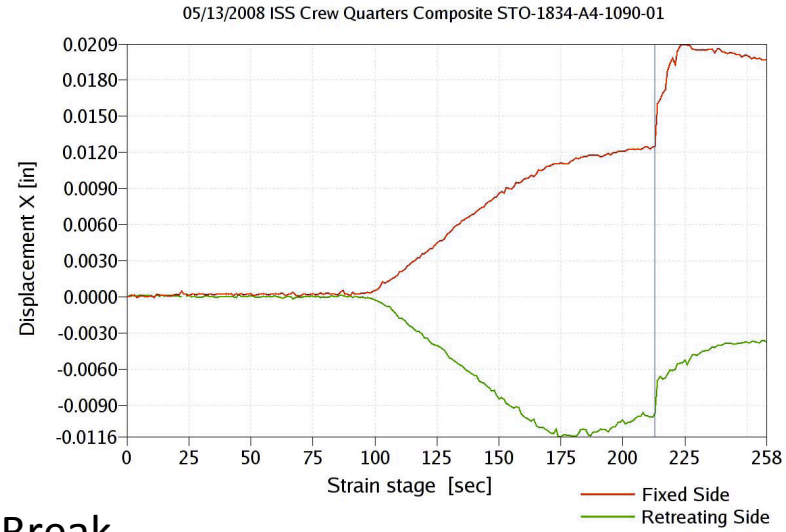


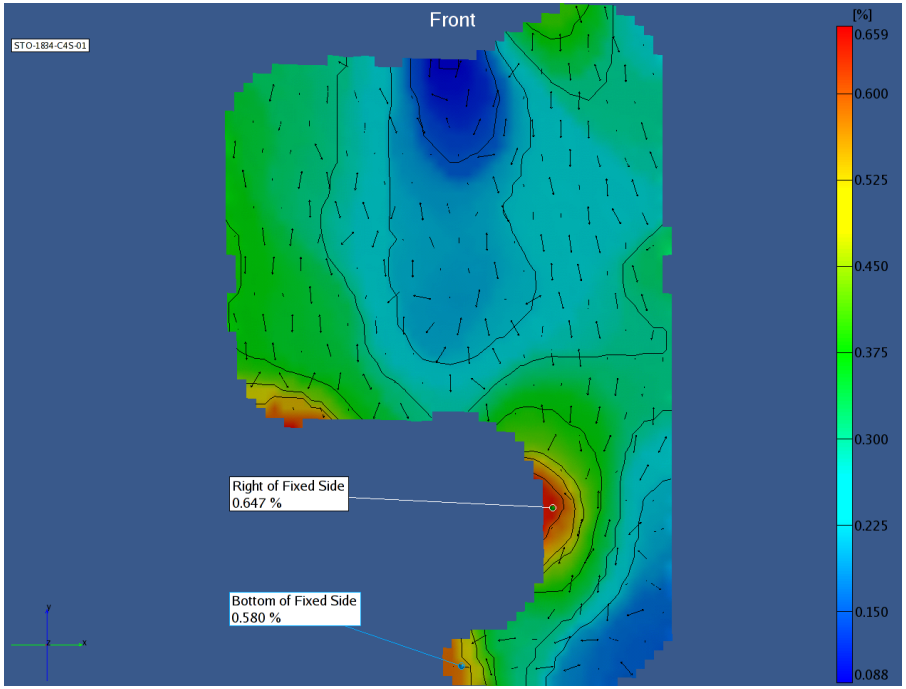
Major Strain Point of View Frame at Break





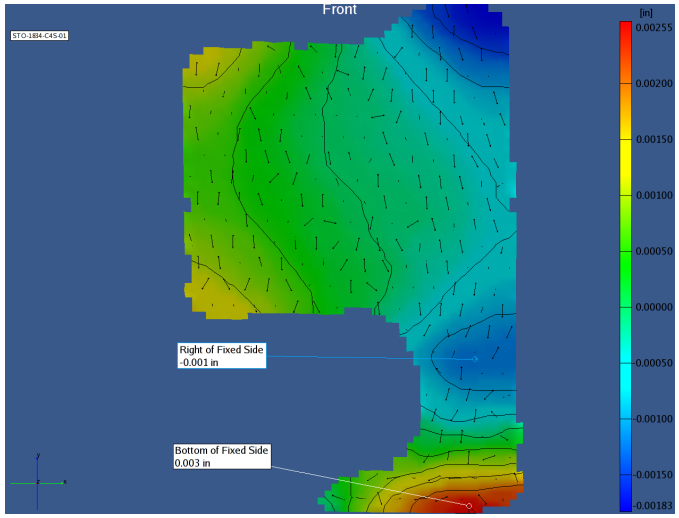
Displacement Field X Point of View Frame at Break



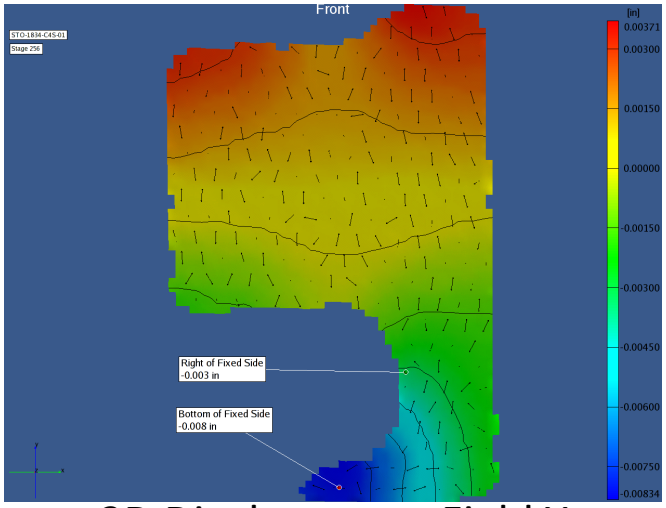


3D Major Strain Field

NAS1834-C4S-01

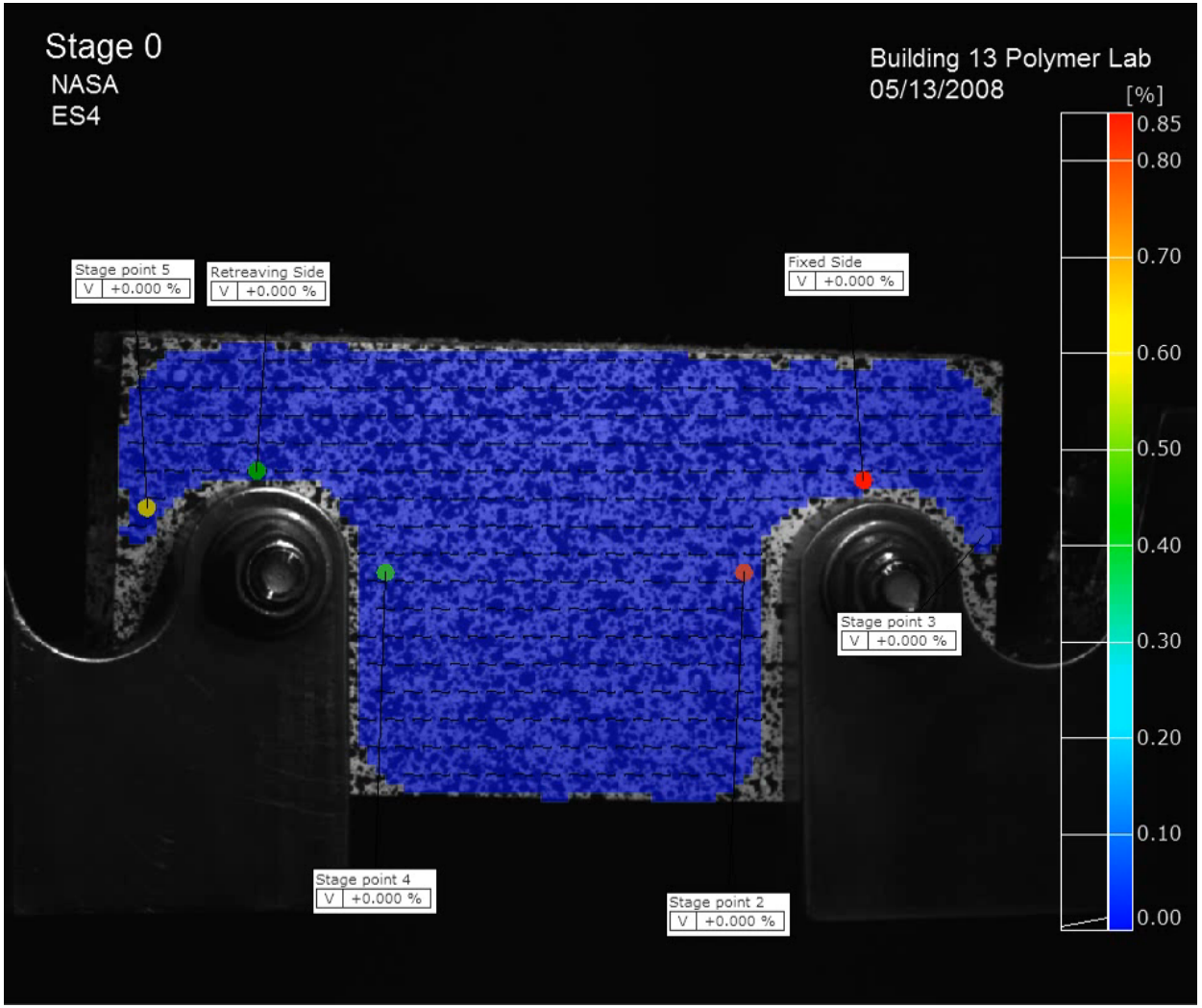


3D Displacement Field X



3D Displacement Field Y

Displacement Field in Sandwich Inserts Under Bearing Load



Shear Bearing Results

Specimen ID	Strain Point	Time	Peak Load	Peak Stress	Modulus
	[%}	[sec]	[Lbs]	[ksi]	[ksi]
STO-1834-A4-1090-01	0.52%	214	3570.2	5.2	175.0
STO-1834-A4-1090-02	0.52%	223	3418.8	5.0	174.0
STO-1834-A4-1090-03	0.49%	192	3518.0	5.1	175.5
STO-1834-A4-1090-04	0.59%	178	3747.9	5.1	175.0
STO-1834-A4-1090-05	0.54%	153	3501.8	5.1	169.4

Conclusions

- Pull-Through
  - High Strain Areas Evident at Insert Edge
  - Major Strain Direction Develops Tangent to Insert
- Shear Bearing
  - High Strain Primarily at Insert Compressive Edge
  - High Percentage of failure load maintained through tear-out
- 100% Inspection of all critical inserts
  - X-ray Difficult to Quantify Porosity
  - Multiple Views not Possible on Most Parts
- ARAMIS Method Excellent for Test Verification
  - FEA Model Correlation Possible
  - Complex Shapes
  - Identify Locations for Strain Gauge

Displacement Field in Sandwich Insert Structural Loading

- Acknowledgements
  - Mike Kocurek (MEL Polymer Lab Technician)
  - NASA JSC Crew and Thermal Systems Division (EC)
  - NASA JSC Structural Engineering Division (ES)
  - Jacobs ESCG and MEI Tech Inc
  - JSC Material Evaluation Laboratory (MEL) and NDE Group

CMH-17
Sandwich Working Group

Thank You

Questions?